



# **Analysis Results for Lunar Soil Simulant Using a Portable X-Ray Fluorescence Analyzer**

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## LIST OF ACRONYMS AND SYMBOLS

Al	aluminum
Ca	calcium
Cr	chromium
Fe	iron
JSC-1	Johnson Space Center number one
K	potassium
Mg	magnesium
Mn	manganese
MSFC	Marshall Space Flight Center
Na	sodium
Ni	nickel
O	oxygen
P	phosphorous
PDA	personal digital assistant
Si	silicon
SiPIN	silicon P-type intrinsic N-type detector
Ti	titanium
TRACeR	taggant recognition and authentication code enabled reader
XRF	x-ray fluorescence





## **TECHNICAL MEMORANDUM**

### **ANALYSIS RESULTS FOR LUNAR SOIL SIMULANT USING THE A PORTABLE X-RAY FLUORESCENCE ANALYZER**

#### **1. INTRODUCTION**

Long-term habitation missions on the Moon will require that natural lunar resources be used to minimize the amount of material and supplies that must be transported from Earth. For example, lunar soil will potentially be used for oxygen generation, water generation, and as filler for building blocks. NASA's in situ fabrication and repair program is evaluating portable technologies that can assess the chemistry of lunar soil and lunar soil simulants. This Technical Memorandum summarizes the analysis results of Johnson Space Center number one (JSC-1) lunar soil simulant using the taggant recognition and authentication code enabled reader (TRACeR™) III-IV handheld x-ray fluorescence (XRF) analyzer manufactured by KeyMaster Technologies, Inc. The focus of the evaluation was to determine how well the current instrument configuration would detect and quantify the components of JSC-1.

## 2. INSTRUMENT DESCRIPTION

The TRACeR III–IV XRF analyzer was selected for evaluation because it provided the capability to detect and quantify elements with relatively low atomic weights including aluminum (Al), titanium (Ti), and silicon (Si) that are significant components of JSC–1. TRACeR is able to analyze for these elements because it generates a vacuum pressure of approximately 1 torr between the detector and the analyzer head by employing a detachable vacuum accessory. Although handheld XRF analyzers were available from several additional manufacturers at the time this study was conducted, they did not have the capability to provide quantification data for Al, Ti, or Si, and therefore were not tested.

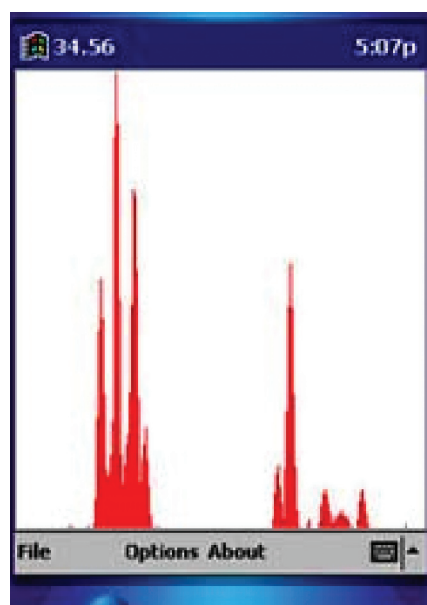
In addition to elemental analysis, the TRACeR III–IV can identify and classify metal alloys. The instrument is programmed with a database of alloy spectra that are mathematically compared to sample spectra to find the best match. Alloy database classifications include iron (Fe), nickel (Ni), and Al. This capability might also prove to be useful during lunar missions if alloy identification is required prior to repair and fabrication operations.

Figure 1 is a photograph of the TRACeR III–IV. The analyzer weighs approximately 4 lb and the analyzer/vacuum pump combination weighs approximately 9 lb. It can be operated using a personal digital assistant (PDA), which is the most portable configuration, and a computer. The instrument uses an x-ray tube as the source and has a Si P-type intrinsic N-type (SiPIN) detector.



Figure 1. TRACeR III–IV portable XRF analyzer.

Figure 2 shows an example of the analysis results as viewed on the PDA screen. An XRF spectrum is provided, along with a breakdown of elemental components and weight percentages.



A screenshot of a PDA screen showing chemistry analysis results. The top status bar displays 'PMI' and '12:52p'. Below the status bar is a title bar labeled 'Chemistry'. The main area contains a table of elemental concentrations. The bottom status bar shows the menu items 'File', 'Options', and 'About', along with a small icon and a right-pointing arrow.

Chemistry	
Ti	0.0510
V	0.0000
Cr	0.0210
Mn	0.9810
Fe	0.6722
Co	0.0000
Cu	32.0330
W	0.0000
Zr	0.0000
Nb	0.0000
Mo	0.0600

Figure 2. Example of analysis results displayed on the PDA.<sup>1</sup>

### 3. TEST DESCRIPTION

JSC-1 powder was analyzed using a data collection time of 180 s per test and an instrument power level of 15 kV. The simulant was analyzed five times and the results were averaged. The vacuum accessory was employed to enhance detection of Al, Si, and Ti. The instrument was operated using a laptop computer rather than the PDA, because the laptop software provided the operator with more flexibility regarding the selection of elements for quantitative measurements.

A calibration model had to be developed to obtain quantitative JSC-1 chemistry information. Feldspar, an aluminosilicate with the general formula  $XAl(1-2)Si(2-3)O_8$ , where  $X$  is sodium (Na), potassium (K), or calcium (Ca), was used to develop the model. Unfortunately, Feldspar was deficient as a calibration material for several reasons. As shown in table 1, it did not contain Ti, manganese (Mn), chromium (Cr), or phosphorous (P) which are all present in JSC-1. In addition, the Feldspar samples were in solid form while JSC-1 exists as a powder, and the XRF analysis can be impacted by a material's physical characteristics. Even though these deficiencies were recognized, a more representative analog of JSC-1 could not be identified.

Table 1. JSC-1 chemistry.\*

Major Components		
Oxide	Concentration (wt%)**	Standard Deviation (wt%)
SiO <sub>2</sub>	47.71	0.1
TiO <sub>2</sub>	1.59	0.01
Al <sub>2</sub> O <sub>3</sub>	15.02	0.04
Fe <sub>2</sub> O <sub>3</sub>	3.44	0.03
FeO	7.35	0.05
MgO	9.01	0.09
CaO	10.42	0.03
Na <sub>2</sub> O	2.7	0.03
K <sub>2</sub> O	0.82	0.02
MnO	0.18	0
Cr <sub>2</sub> O <sub>3</sub>	0.04	0
P <sub>2</sub> O <sub>5</sub>	0.66	0.01
Total = 98.94		
JSC-1 Trace Elements		
Element	Concentration (ppm)**	Standard Deviation (ppm)
Scandium	29.2	0.5
Cobalt	47.7	1.6
Nickel	137	18
Rubidium	12.3	1.5
Cesium	0.339	0.01
Strontium	860	36
Barium	822	13
Lanthanum	48.2	0.9
Cerium	94.6	1.7
Neodymium	42	2
Samarium	7.44	0.13
Europium	2.18	0.04
Terbium	0.825	0.01
Ytterbium	1.99	0.04
Zirconium	125	3
Hafnium	3.55	0.08
Tantalum	1.96	0.04
Uranium	1.51	0.08
Thorium	5.65	0.07
Arsenic	18.7	8.9
Selenium	<0.5	0
Antimony	0.564	0.57
Tungsten	36.1	2.6
Gold	40.7	29.4
Bromine	0.85	0.07
Lutetium	0.293	0.01

\* Source—McKay, D.S.; Carter, J.L.; Boles, W.W.; Allen, C.C.; and Allton, J.H.: "JSC-1: A New Lunar Soil Simulant," *Engineering, Construction, and Operations in Space IV*, American Society of Civil Engineers, pp. 857–866, 1994.

\*\* Wt% and ppm data are the mean of three analyses.

## 4. TEST RESULTS

A representative XRF spectrum of JSC-1 obtained using the TRACeR III-IV is shown in figure 3, and table 2 summarizes the analysis results. Only the major elemental constituents including Na, Al, Si, K, Ca, Fe, and magnesium (Mg) could be detected and quantified. Mn and Ti were detected but could not be quantified since they were not included in the calibration model. Cr, P, and the numerous JSC-1 trace elements were below the instrument's detection limits.

Standard deviation values for the measured weight percentages were low, which indicated that analysis results were consistent for multiple scans of JSC-1. The percentage error values for chemistry composition were very high, which was due in part to the nonoptimized calibration model.

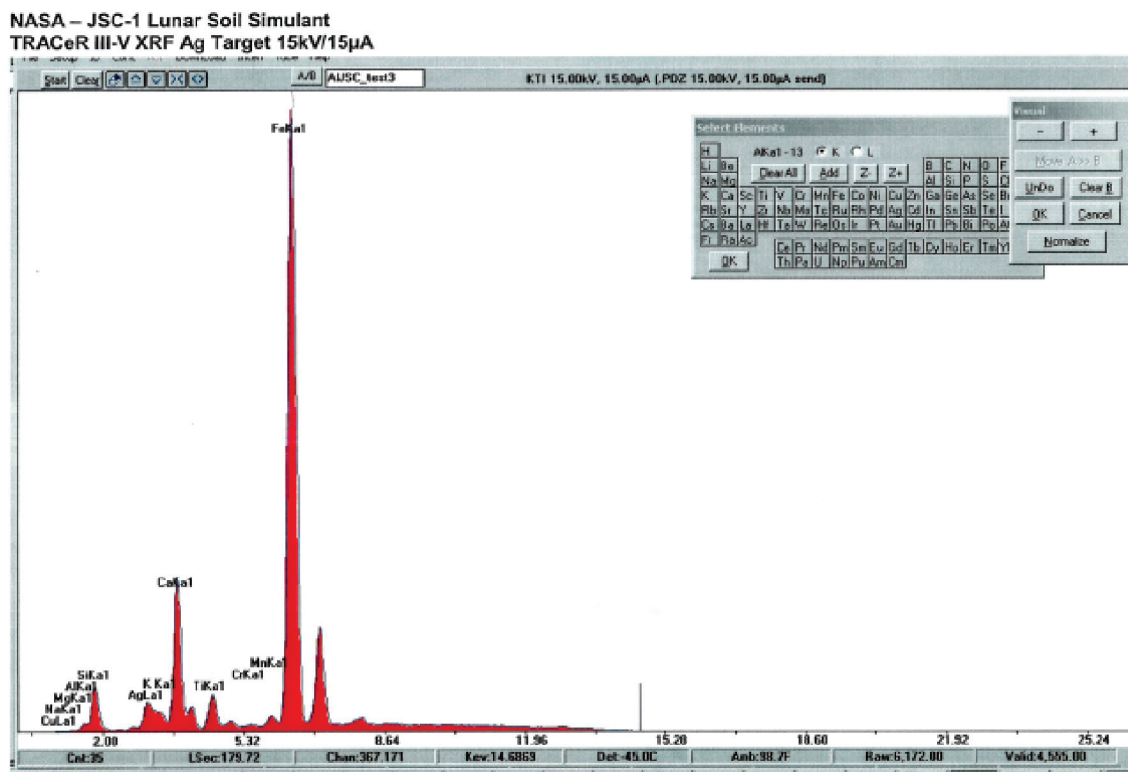


Figure 3. Example XRF spectrum of JSC-1.

Table 2. JSC-1 analysis results using the TRACeR III-IV.

Test No.	Measured Wt% of Detected Elements (Present as Oxides)						
	Na	Mg	Al	Si	K	Ca	Fe
1	1.55	10.03	12.53	34.51	0.1	12.21	16.16
2	1.59	11.15	12.02	34.55	0.17	12.42	15.13
3	1.67	12.87	11.51	34.55	0.12	12.16	15.35
4	1.61	12.47	11.56	34.47	0.06	11	16.12
5	1.59	10.41	12.28	34.49	0.04	11.48	16.16
<b>Average</b>	1.6	11.38	11.98	34.51	0.1	11.85	15.78
<b>Standard Deviation</b>	0.04	1.25	0.44	0.03	0.05	0.59	0.5
<b>Accepted Value</b>	2.7	9	15	47	0.8	10.4	10.8
<b>% Error</b>	41%	-26%	20%	27%	88%	-14%	-46%

## 5. CONCLUSIONS

The TRACeR III–IV portable XRF analyzer was only able to detect and quantify constituents of JSC–1 that were present at weight levels of approximately 1–2 percent and higher. KeyMaster, the manufacturer, advised that quantification of Mn and Ti would likely be possible if they were included in the calibration model. However, responses for Cr, P, and the trace elements would likely remain below detection limits even with enhancement of the model. The instrument was stable in that repeated JSC–1 analysis provided consistent quantitative chemistry values.

Three significant efforts would be required to bring the TRACeR III–IV to a status more suitable for lunar missions: (1) PDA software modification to incorporate the JSC–1 analysis protocol, (2) development of an XRF standard, similar to JSC–1, and (3) refinement of the calibration model.



## **REFERENCES**

1. "The Lab," KeyMaster Technologies, Inc., <http://www.keymastertech.com/lab.html>, accessed October 31, 2006.

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